INEEL/CON-00-01061
PREPRINT

Idaho National Engineering and Environmental Laboratory

Automated Sorting Of Transuranic Waste

Rodney M. Shurtliff

March 4, 2001

The American Nuclear Society – 9th Topical Meeting on Robotics and Remote Systems

AUTOMATED SORTING OF TRANSURANIC WASTE

Rodney M. Shurtliff
Advisory Engineer
Idaho National Engineering and Environmental Laboratory
2525 Fremont Ave.
Idaho Falls, Idaho 83415-2220
Voice: (208) 526-3325
Fax: (208) 526-7688
Email: rshurtli@inel.gov

ABSTRACT

The HANDSS-55 Transuranic Waste Sorting Module is designed to sort out items found in 55-gallon drums of waste as determined by an operator. Innovative imaging techniques coupled with fast linear motor-based motion systems and a flexible end-effector system allow the operator to remove items from the waste stream by a touch of the finger. When all desired items are removed from the waste stream, the remaining objects are automatically moved to a repackaging port for removal from the glovebox/cell.

The Transuranic Waste Sorting Module consists of 1) a high accuracy XYZ Stereo Measurement and Imaging system, 2) a vibrating/tilting sorting table, 3) an XY Deployment System, 4) a ZR Deployment System, 5) several user-selectable end-effectors, 6) a waste bag opening system, 7) control and instrumentation, 8) a noncompliant waste load-out area, and 9) a Human/Machine Interface (HMI). The system is modular in design to accommodate database management tools, additional load-out ports, and other enhancements.

Manually sorting the contents of a 55-gallon drum takes about one day per drum. The HANDSS-55 Waste Sorting Module is designed to significantly increase the throughput of this sorting process by automating those functions that are strenuous and tiresome for an operator to perform. The Waste Sorting Module uses the inherent ability of an operator to identify the items that need to be segregated from the waste stream and then, under computer control, picks that item out of the waste and deposits it in the appropriate location. The operator identifies the object by locating the visual image on a large color display and touches the image on the display with his finger. The computer then determines the location of the object, and performing a high-speed image analysis determines its size and orientation, so that a robotic gripper can be deployed to pick it up. Following operator verification by voice or function key, the object is deposited into a specified location.

1. INTRODUCTION

The Automated Waste Sorting Station provides operator assisted automation to the process of sorting waste. Backup capabilities provide the operator several options for recovery in the event an object cannot be detected by the Sorting Station Imaging System. In these fall-back modes, the robotics of the system are still used to provide a less fatiguing approach to waste sorting than currently used in the industry.

The technology is applicable in contact handled and remote handled waste applications. The hardware currently being developed is scheduled for deployment in a contact-handled environment which will provide refinement opportunities not available in a remote-handled waste environment. This first deployment will serve as a test bed to prove the technology and will become a stepping stone towards the ultimate goal of fully automatic sorting.

The Sorting Station hardware has been designed for remote cell maintenance. A minimum of moving parts have been used in the robotic positioning system; no moving parts exist in the imaging system; and where possible, serviceable parts have been located outside the contamination control barriers. Custom software has been developed to provide technicians with powerful tools to troubleshoot components of the system and quickly identify problems should they arise.

A variety of end-effectors or robotic tools have been interfaced with the robotic motion platform, termed the XYZR Deployment System. A general purpose gripper has several programmable grips which allow this end-effector to be used to pick up a variety of objects. A quick change plate interface on the Z-Mast allows other end-effectors to be exchanged automatically if the operator deems it advantageous to do so. End-effectors developed include a suction cup, electromagnet, calibration device and a manual sort bin.

A stereo vision measurement system has been designed in partnership with a commercial vendor that provides extremely rapid profiling of objects on a sorting table. The profile information is used to define an object adequately enough to pick up the object with the XYZR Deployment System. A specialized method of light projection works with the stereo measurement system to create the image contrast necessary to assure measurement data for the objects located on the table.

The sorting table provides a quick method of clearing the waste in the instances where a few noncompliant items need to be removed from the waste and the rest of the waste moved to the repackaging module. The table is capable of tilting and vibrating to move waste into a new container.

The Waste Cut Bag Opener is a device designed to open the individual waste bags as they are dumped onto the sorting table. It works in conjunction with the robotic system and has capabilities to open the tops of the bags or a more complex cut is possible with interchangeable end-effectors. A vertical deployment system positions the cutting device and a lateral deployment system stows the cutter in a safe position.

2. BACKGROUND

The U.S. Department of Energy (DOE) analyzed the need complex-wide for remote and automated technologies as they relate to the treatment and disposal of mixed wastes. This analysis revealed that several DOE sites need the capability to open drums containing waste, visually inspect and sort the contents, and finally repackage the contents into containers that are acceptable at a waste disposal facility such as the Waste Isolation Pilot Plant (WIPP) in New Mexico.

Specifically, the Savannah River Site (SRS) waste inventory includes approximately 10,000 55-gallon drums that need to be processed in this manner (i.e., open the drums, inspect them, sort, and repackage the contents). Accordingly, the Mixed Waste Focus Area and the Robotics Technology Development Program are co-funding the development of a facility to provide these functions. This facility will initially be deployed at the SRS by the year 2004.

The waste expected in the SRS drums is classified as Transuranic (TRU) waste, with some materials regulated by the Resource Conservation and Recovery Act (RCRA). The waste is classified as (CH—defined as waste having radioactivity levels below 200 mrem/hr), and although the radioactivity levels are relatively low, handling TRU waste poses a health hazard to the worker. The TRU particles can produce serious damage if they are inhaled, ingested, or otherwise carried inside a human or animal organism and allowed to interact with internal organs. Currently, personnel working in a TRU environment must wear full personal protective equipment (PPE), making the work cumbersome and time consuming.

The Pacific Northwest National Laboratory (PNNL) also needs a system to perform similar functions. However, PNNL waste includes mostly remote-handled (RH) waste (as opposed to the CH waste at SRS). Combining these needs, the DOE has decided to design the HANDSS-55 hardware for the RH needs at PNNL, yet initially deploy the system at SRS where the waste and hardware can be contact-handled, offering a lower-risk test bed.

In summary, the design direction for the HANDSS-55 is as follows: to develop a remotely operated and maintained system to open drums and liners and sort and repackage RH waste that will initially be deployed in a CH environment. The HANDSS-55 will include multiple modules, each performing discrete functions. Some of the main modules are (1) system integration (2) the visual inspection and Waste Sorting Module including the Automated Drum and Liner Opener (AD&LO), (3) the TRU Waste Repackaging Module (TWRM), and (4) the Process Waste Reduction Module (PWRM).

The Waste Sorting Module focuses on the hardware and software system that will allow an operator to (1) open the 55-gallon drum and internal liner, 2) segregate WIPP noncompliant items from the waste stream, and (3) visually inspect and segregate TRU waste ultimately destined for WIPP storage.

3. SORTING STATION COMPONENTS

The components of the HANDSS-55 Sorting Station consist of the Sorting Table, XY Deployment System, ZR Deployment System, multiple end-effectors and end-effector storage racks, Imaging System, Operator Interface, and Waste Cut Bag Opening System. Each component interfaces with the other components of the system to form the integrated system used to sort waste

Coordination of the component operations of the Sorting Station is required to avoid damage to the equipment. A process flow sheet has been incorporated into the control software to preclude inadvertent movement of the components. The control system must grant permission before a component is allowed to perform a function.

3.1 Sorting Table

The stainless steel Sorting Table is designed to hold the full contents of a 55-gallon drum (approximately 7.1 cubic feet). If the debris on the table is spread out evenly, it will be about four inches deep. The debris will be loaded onto the table from one end using drum handling equipment and the waste will be moved off of the table into the TRU Waste Repackaging Module (TWRM) on the other end.[1] The sides of the table are 8 inches high on both sides and one end. At the open end there is a moveable endgate made from 1/8 inch thick 304 stainless steel that is tapered to a 20 inch diameter circular hole through which the sorted waste will drop into the TWRM liner. The moveable endgate pivots about the lower edge of the Sorting Table end, allowing it to close the opening when waste is being dumped onto the table. This endgate will also be pivoted up when a new TWRM drum is being installed. When the endgate is up the closure is not a liquid tight seal but it will keep objects from falling off the table. During the sorting operation, the endgate can and will likely be down so that items can be placed in the TWRM drum as required. After all noncompliant items are removed, the endgate must be down so that the remaining waste can be moved into the TWRM liner. To facilitate the movement of materials from the table to the TWRM, tilting and vibrating mechanisms have been incorporated into the table design. The tilting and vibrating mechanisms can be activated automatically by the Waste Sorting Station control system (remotely located in a central control room) or locally via the Local Operator Control Stations (LOCS), which will be located on the outside wall of the glovebox. The table will tilt down, sloping away from the TWRM (-2 degrees) during waste loading to preclude any free liquids from running into the waste load-out port. The table can be tilted towards the TWRM at an angle up to 28 degrees. A vibrator mechanism attached to the bottom of the Sorting Table can be activated to aid in moving the waste towards the TWRM

3.2 XY Deployment System

The XY Deployment System is the motion platform by which the robotic end-effector is accurately positioned over the Sorting Table. Motion in both X and Y directions is accomplished using three-phase linear servo motors. Linear motors have no moving parts and were chosen for reliability and simplicity of design. The X-axis motor is an AC induction type while the Y-axis motor is a DC iron core brushless type.

The X-direction of the XY Positioning/Deployment System (also called XY System) is horizontal and parallel to the length of the Sorting Table. The Y-direction of the system is also horizontal but perpendicular to the X-direction as shown in Figure 1. The motor coil is carried by the moving platform above the steel/magnetic track. Stainless steel wheels have an eccentric built into their mounting shaft so the height of the coils above the steel/magnetic tracks can be adjusted to the required distance. The gap between the motor coils and the track affect the efficiency of the motor operation at some point, but typical spacing in the system is about ¼”.

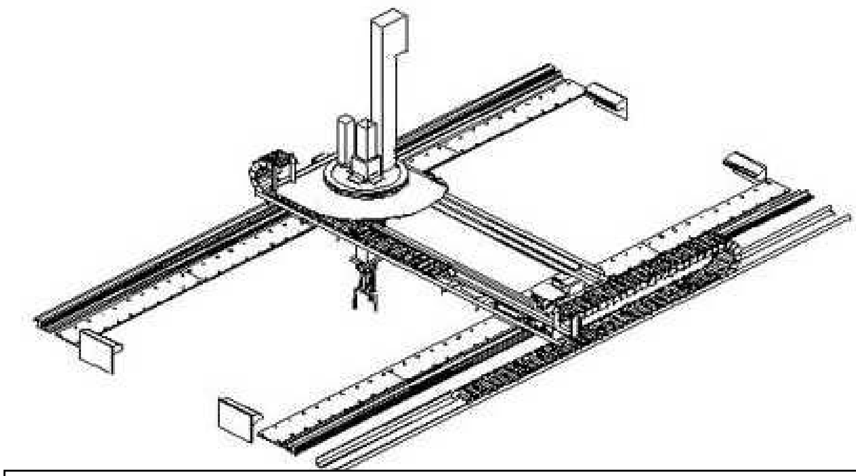

Figure 1. Overview of XY System with Z-Mast and End-effector Installed

The X-motion platform, or bridge, is mounted on stainless steel wheels, which roll on stainless steel rails supported by the glovebox structure. The Y-motion platform, or trolley, is mounted on stainless steel wheels, which roll on stainless steel rails that are mounted on the bridge. The rail and wheels at one end of the bridge and one side of the trolley have a mating “V” shape to guide the platform as it moves on the rails. Flat rails and wheels are used at the other ends to accommodate any nonparallelism that may exist between the rails. Two main wheels are used at each end of each platform to support the vertical load and two smaller wheels are used under the rail structure at each end of each platform to prevent it from coming off the rails. None of the smaller wheels are “V” shaped and they are adjusted to contact their running surfaces only at the tightest spot of each track. Therefore, they will not be turning constantly and the load will be light.

Two linear servo motors are used on the bridge. Because of the high width-to-length ratio of the bridge, a motor is used at each end to keep the bridge square with the rails. However, testing of the system has shown that one motor at either end moves the bridge smoothly. Each end of the bridge has a magnetic position encoder and the two motors can operate in a master/slave configuration or in a parallel mode where one control voltage drives both servo amplifiers. Smoothest operation is accomplished using the latter mode. Induction motors were chosen for the bridge drive because of the length required for the magnetic track (2×16 feet). Induction linear motors use a 1/8-inch aluminum plate over a 1/4-inch carbon steel plate for their magnetic coupling track. This is much less expensive than a permanent magnet track. The aluminum and carbon steel could be overlaid with a thin gauge stainless steel for corrosion protection. The linear induction motors used are Northern Magnetics[2] (a division of Baldor) model 06513 and the position encoders are EMIX3[3] integrated sensor heads over magnetic tape sandwiched between stainless steel protective layers.

All the wheels used on this system are of the Load Runner series from Osborne Manufacturing of Cleveland, Ohio. The main wheels have tapered roller bearings and the smaller ones have ball bearings. Each bearing is lubricated with Micropoly™ from PhyMet Incorporated of Springboro, Ohio. Micropoly™ is an oil saturated polymer custom shaped to fill all of the bearing cavities. It releases the lubricant as the bearing is operating and then reabsorbs it as it cools. This product reduces bearing contamination and loss of lubricant, ensuring that these bearing can operate for their total rated life without routine maintenance. If the bearings were operated at the system's maximum speed and maximum load continuously, their calculated life would be 130,000 hours. At average speed and average load their calculated life is 300,000 hours.[a]

Because the trolley is a smaller, nearly square platform, a single linear servo motor is used. Since the y-motion travel is only 67 inches, a permanent magnet track and an iron core motor are cost effective. This configuration gives more power in a smaller package, which is required for the trolley drive. The permanent magnet track is composed of rare earth magnets bonded to a hard-chromed cold rolled steel plate. This assembly could be covered with a thin gauge stainless steel for corrosion protection. The motor used on the trolley is a Northern Magnetics model BL10. The trolley uses an LMIX3 position sensor similar to those used on the bridge, but with a relaxed gap requirement and less resolution. The LMIX3 could be used for the bridge as well since it still provides a resolution of 25 microns (0.001"). The resolution of the EMIX 3 encoders is 0.0004 inch and the positioning accuracy of the linear motors with vector controllers is within 0.039 inch (1 mm). Because of the distance between the servo amplifiers and the encoders, a 24VDC power supply version of the encoders with a 5VDC output was chosen.

For a 50% duty cycle (on for no more than 15 seconds out of each 30 second interval), each linear induction motor can generate up to 54 pounds of linear force. This means that the two motors can accelerate and decelerate the bridge and everything mounted on it (1100 lb) at 0.10 g which would move it 15 feet from a standstill and stop again in 4.4 seconds, reaching a peak speed of 6.9 feet per second. This could be done once every 8.8 seconds without overheating the motors. For a 100% duty cycle, the maximum acceleration is 0.04 g, which would move it 15 feet from a standstill and stop again in 6.7 seconds, reaching a peak speed of 4.4 feet per second.

For the trolley, the permanent magnet linear motor can also develop up to 54 pounds of force at 50% duty cycle. This equates to an acceleration/deceleration of 0.11 g for the 500 pound weight of the trolley and everything that's mounted on it, which means it could move 5 feet from standstill to stop in 2.4 seconds, reaching a peak speed of 4.2 feet per second. The power rating curve for the permanent magnet motor is better than for the induction motor (it would only drop to 0.08 g at 100% duty cycle). This means it would take 2.9 seconds to move 5 feet from standstill to stop, reaching a peak speed of 3.5 feet per second.[b]

Cable management for both the bridge and trolley is done with Igus polymeric cable chain. For the bridge, the cable chain is mounted on the temporary support structure and, for the trolley, the cable chain is mounted on the bridge.

Spring actuated, pneumatic released caliper brakes are used on both the bridge and trolley for fail safe braking. In case of power failure, these brakes will bring both moving platforms to a

---

[a] Scott Allen, Steven Hills, Michael Gifford, Rodney M. Shurtliff, Marcela Stacey, Steven Swanson, Miles Walton, "Transuranic Waste Sorting Module for the HANDSS-55", Appendix D1, page 4, Idaho Nation Engineering and Environmental Laboratory, Idaho Falls, Idaho, 1999.

[b] Ibid, pg. 5

quick stop. The brakes used are model MUS-2 from the Hilliard Corporation, Elmira, New York. There is one caliper at each end of the bridge and one caliper on the trolley. These calipers travel over and can grip a linear rail that is mounted to the stationary base below each platform. Each caliper generates 135 pounds of braking force. This is more deceleration force than the linear motors can supply. During operation, the speed of the moving platforms will be controlled so that they can be stopped by the motors before reaching the end of the rails. Therefore, the fail-safe brakes can also always stop them before reaching the end of the rails. Should these brakes fail, there are rubber bumpers at the end of the rail travel to stop the moving platforms. If this happens, the moving platforms cannot come off the rails. The worst case scenario is that the end-effector and/or load it is carrying would impact the side of the glovebox.

Limit switches are mounted at each end of each set of rails to prohibit travel outside the normal operating range. Trolley or bridge travel in the limit switch direction is curtailed by the servo amplifier without software intervention when the switch is activated.

3.3 ZR Deployment System

The Z-Mast Deployment System is a unit designed to provide two additional degrees of freedom to the X-Y Positioning/Deployment System, thus allowing precise positioning of the end-effectors with four degrees of movement. The Z-Mast Deployment System provides the vertical and rotational capabilities of the XYZR-Deployment System. The Z-Mast Deployment System mounts directly on top of the trolley for the X-Y Positioning/Deployment System as shown in Figure 2.

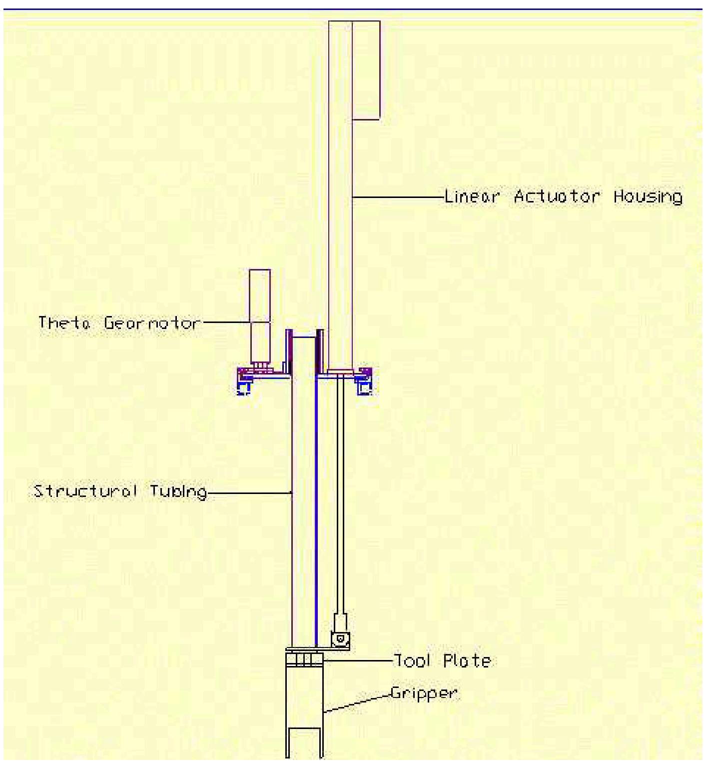

Figure 2. Side View of the Z-Mast Deployment System

The main components of the equipment include a linear actuator, servo gearmotor, gear set, polymer bearing sheets, stainless steel structural tube, and a large rotating ring and housing. It is the large bearing retention ring, which forms the base for the vertical mast, linear actuator, and theta rotational equipment.

The general development of the Z-Mast Deployment System was determined by several major design constraints. These major constraints include:

- Lifting a 200 lb load

- Positioning the universal End-Effector to within .05” of the target (both vertically and rotationally)

- Providing a 100 lbf side-load capability for moving items on the table

- Allowing the universal End-Effector to access objects next to the Sorting Table walls

- Lifting the universal End-Effector over a 36” stroke in 3 seconds or less

- Rotating the universal End-Effector 180° in 3 seconds.

To allow the end-effector to access objects next to the walls of the Sorting Table, the Z-Mast structure could not exceed the 6” diameter of the end-effector and tool changer. A search was conducted to find equipment that could rotate the gripper without exceeding the 6” diameter. No equipment was found capable of meeting this constraint, while providing the load lifting capabilities that were previously discussed, as well as providing a workable cable management scheme. As a result, the rotational components of the Z-Mast were moved to the upper portion of the overall assembly.

To provide a 100-lbf side load capability to the Z-Mast, a stout and rigid structure is required. Linear actuators are the preferred drive mechanism for the vertical motion, as they are reliable, easy to maintenance, cost-effective, and commercially available. The insufficient side load capability of a standard linear actuator was improved by adding a commonly used structural tube and bearing system. The current system was custom designed, as no commercial available models were found to meet the design requirements.

It is important during a sorting operation to know the weights of the objects that are being sorted or visually inspected. To facilitate this function a force/torque sensor made by JR3 Inc., was designed into the Z-Mast, just above the tool change plate. The sensor is capable of measuring the force on three orthogonal axes, and the moment (torque) about each axis. Besides providing the weighing function, the sensor will provide a method of safeguarding the end-effectors on the end of the Z-Mast and the Z-Mast itself by looking for out-of-limits conditions. The data is digitized within the sensor and sent to the control system in an RS485 serial link, providing a low noise system. Because of the cable distances required by the cable management systems, an analog low level signal would be difficult to interface to the control system without severe signal degradation.

Plans are underway to replace the Z-Mast system with a telescoping Z-Mast which has the capability of reaching into the TWRM for recovery of objects that may have inadvertently been dropped into the liner. This will be fabricated and installed in FY2002.

3.4 End-Effectors/Storage Racks

Multiple end-effectors can be used with the Z-Mast assembly. A quick change tool plate manufactured by Techno-Sommer Corporation[4] was modified to meet the requirements of the Sorting Station. It provides rapid end-effector exhange and provides electrical and pneumatic connections to the end-effectors. Each end-effector has been interfaced to a tool plate. Each tool side tool plate is mounted to a triangular plate specially designed to mate with an end-effector storage rack. This provides a means of storing the end-effectors not in use in such a manner that they can be remotely coupled/decoupled.

Barrett Technologies[5] of Cambridge Massachusetts manufactures a robotic hand that has procured for incorporation into the Sorting Station. This hand, referred to as the BarrettHand™, (Figure 3) is the only one of its kind that is commercially available. Flexibility and programmability drove the decision to use the BarrettHand™ rather than a less expensive parallel gripper. Parallel grippers are custom designed to pick up specific shapes and sizes. In the Sorting Station the shape and size of the objects of interest are largely unknown. Using the BarrettHand™ will reduce the number of end-effectors needed in the system, thus decreasing the time required to change out end-effectors. The BarrettHand™ essentially matches the functionality of an assortment of custom grippers. All of the control electronics including servo motor drivers and encoders are contained within the housing of the BarrettHand™, creating a very compact and electronics interface consists of two power supply connections and a serial communications interface (RS232). Figure 3 shows the robotic hand in a fully closed position. The two outside fingers can be moved in an arc from zero to 180°. This provides a method of changing the grip of the robotic hand. Round, tubular, rectangular, square, and compound-angle objects can be grasped with the BarrettHand™. Items having various mass and fragility from lead bricks to light bulbs can be picked up. Part of this flexibility is due to the unique finger design of the hand. A torque sensor within the finger joint stops the movement of the first joint while allowing the second joint to continue to wrap around the object being grasped. This wrapping motion allows a much greater payload to be lifted than would otherwise be possible. The hand has been tested to a payload of 50-lbs. A second generation hand is presently being developed by Barrett Technology which will be twice as large as the present hand with four to five times the load capacity.

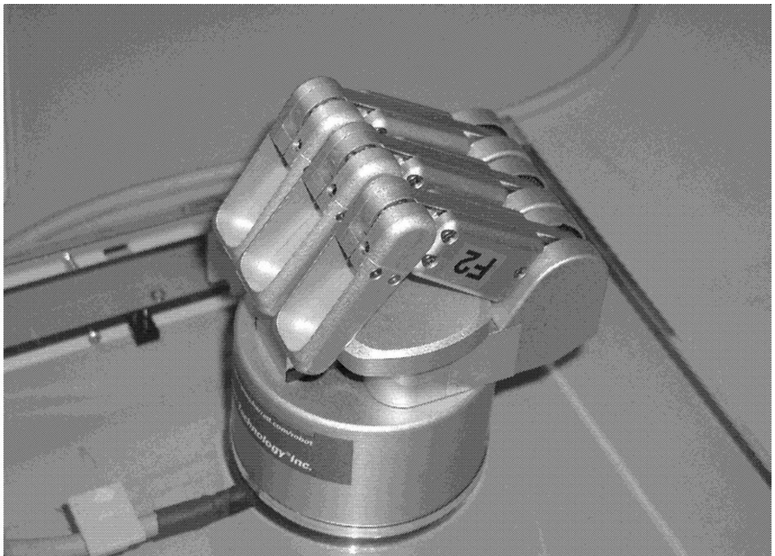

Figure 3. BarrettHand Gripper

Figure 4 shows the triangular mounting plate resting in the storage rack. The plate, termed a delivery plate, is manufactured by Techno-Sommer, but is custom milled to adapt to whatever end-effector is required.

The storage rack design incorporates a floating platform held in position by a spring arrangement. This floating action provides approximately ¼" of compliance in each direction which helps to assure that tool plates or end-effectors are not damaged if some positioning error occurs.

Gross alignment of the tool plates occurs when two large beveled pneumatic connections located on the robot-side tool plate are aligned with the mating female connectors on the tool-side tool plate. The electrical connector on the robot-side tool plate has its own bayonet pins which align

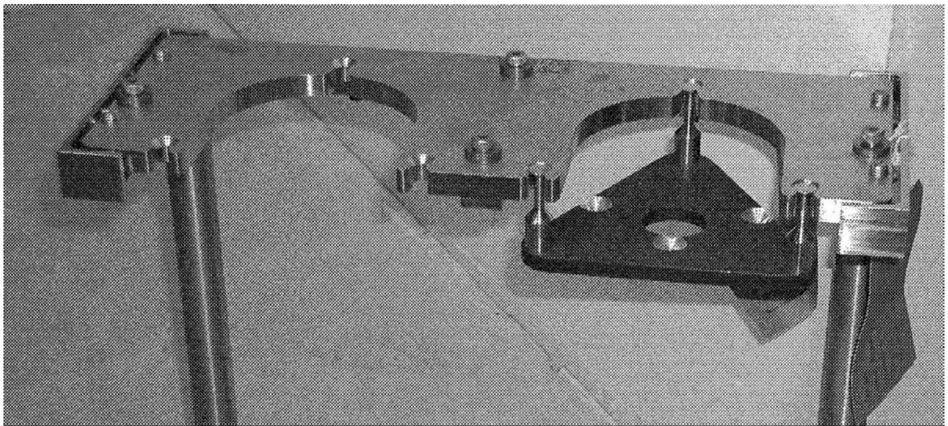

Figure 4. End-effector Storage Rack and Delivery Plate

a compliant connector located on the tool-side tool plate after the gross alignment occurs. The tool plate is coupled by actuating an solenoid located inside of the robot-side tool plate. Approximately 3/16" gap between tool plates can be tolerated during coupling.

3.5 Stereo Measurement/Imaging System

The Stereo Vision Measurement and Imaging System consists of several cameras, each with a specific purpose of either providing information for control of the automated hardware or operator surveillance of the sorting operation. The measurement system will be mounted on top of the containment cell and will view the Sorting Table through a optically clear glass window.

Several technologies were thoroughly investigated, including scanning lasers before making the decision to go with stereo vision measurement. There were many considerations, but the most important were:

- Laser systems that would be able to profile the table contents from a distance of ten feet were fairly high power which created an eye safety consideration.
- Laser systems (except for some $140K programmable types) had difficulties detecting reflective objects
- In order to achieve acceptable XY accuracy, data acquisition times were greater with laser scanners (considering the size of the sorting table) than with stereo vision
- .No laser systems could be found that had the "Z" resolution at a ten foot distance that is achievable with the stereo vision system.
- Periodic calibration of the systems would be necessary to validate measurement data and maintain accuracy. The stereo vision system has built in self-calibration.

A high-resolution stereo vision measurement system (StarCam™) has been developed for the Waste Sorting Module. The development was conducted in two phases. During the first phase, the concepts regarding the image processing method using a dot projection technique and the commercially available monochrome StarCam™ system (see Figure 5) was proven and performance was evaluated. During the second phase the StarCam™ measurement system was redesigned by VX Optronics Inc.[6] to INEEL specifications to integrate a high resolution color CCD, two monochrome CCDs, custom lenses for increased viewing angle, and a high speed digital bus to meet the requirements for the Sorting Station.. The new StarCam™ system transmits digital images via the IEEE-1394 video bus standard (FireWire) at 400 Mbps. INEEL has developed a dot projection system to be compatible with the StarCam™ control interface. The enhanced system from the second phase development will integrate all of the components needed for the imaging process into a compact system.

The StarCam™ system will provide X, Y, and Z coordinates to the control system which will be used to position the XYZR Development System (DS) and configure the end-effector for picking up noncompliant items from the Sorting Table. A correlated color image will be delivered to the touch screen display. From this color image an operator will be able to choose the noncompliant objects that need to be removed from the waste stream. A method of auto calibration of the measurement system is built into the StarCam™, precluding the necessity of periodic calibration using an in-cell calibration source.

Figure 5. StarCam Stereo Measurement System

By touching the image on the screen, the operator will indicate to the computer the object that is to be picked up. When the screen is touched, a region of interest is defined for the image processing software and parameters including color, contrast edge detection and Z profile information are utilized to define the image within the specified region of interest. The object as defined by the software is then outlined on the display including proposed grip points to provide visual feedback to the operator. Assuming the correct object was identified and the grip points acceptable, the XYZR DS will position the end-effector to pick up the object. If the correct object was not identified, the operator will have several options available to him. First, he can tell the computer to try again, and the software will attempt to refine its original object definition. Secondly, he may choose to outline the object himself using the touch screen or the computer mouse. If the outlined object was correct, but the grip points in question, the operator has the ability to designate new grip points with the mouse or with his finger. As a final option, he could move into the tele-operative sorting mode and using the 3-D display, pick up the object using the four axis joystick controller.

Special-purpose imaging software will provide information to the computer to allow the end-effector to be configured appropriately to pick up an object. Gripping force of the end-effector is dynamically set by the operator using a touch screen control button. Pressure sensors located on the gripper fingers provide an analog pressure feedback to the control system. This allows the system to pick fragile items as well as heavy solid objects. The grip points selected will depend on the end-effector in use at the time. Each end-effector has a unique identification number which allows the system to set parameters based on specific end-effectors. This identification number is automatically sensed when the end-effector is coupled to the tool plate.

The operator may change end-effectors by touching a function key on the operator display and selecting the end-effector available to him. The software knows which end-effectors are present in the system by sensors located on the end-effector storage racks.

A stereo camera pair will be mounted adjacent to the Z-Mast to provide stereo vision wherever the end-effectors are used. The stereo or 3-D images will be displayed on a DTI[7] 18" 3-D flat panel monitor which will be mounted adjacent to the Waste Sorting Module control computer. This will provide the necessary depth perception to the operator when in the tele-operative sorting mode without the use of special 3-D glasses.

Additional color cameras equipped with pan/tilt/zoom will provide the operator with a close-up view of the object as it is picked up, allowing a visual verification that the end-effector has picked up the designated object. It will also allow a close-up view for simple identification if the operator is having difficulty identifying an object.

To enhance the ability to obtain Z or depth information from the StarCam™ Module, a video projection system projects a computer generated dot array onto the surface of the Sorting Table which is captured by the camera system. The dot array creates a textured surface from which an accurate depth reading can be obtained. The dot projection is done in two stages: a coarse dot array followed by a fine dot array. The coarse dot array is used to provide an accurate field of reference for the fine dot array. The distance between the projected dots using the fine dot array at a height of ten feet is approximately 20 mm. The dots are approximately 4-mm in diameter. A method for improving the XY resolution, or in other words, to increase the number of XYZ coordinates that can be calcuated, by a factor of four has been developed. The tradeoff is that greater resolution requires more time to process the data. The depth measurement resolution or "Z" is approximately 2 mm.

The IEEE-1394 interface will eliminate the need for a frame-grabber board and will provide full-motion video to the Sorting Station control system. Using fiber optic network adapters[8] the control system can be located as far as 500M from the StarCam™ and is capable of a data transfer rate of 400Mbps (million bits/second).

Lighting must be controlled by the computer to assure the dots can be seen and also to collect a good color image of the objects. This is accomplished by a custom Pulse Width Modulated (PWM) light control system. Under RS232 or IEEE-1394 control, the intensity of the halogen lights arranged around the StarCam can be adjusted from off to full brightness.

3.6 Waste Cut Bag Opening System

The Waste Cut Bag Opener (WCBO), shown in Figure 6, is a unit designed to open all of the PVC/polyethylene waste cut bags located inside of a 55-gallon drum and liner. The system will accommodate all of the individual waste cut bags that contain Transuranic waste. The WCBO has a servo controlled vertical deployment to allow versatility in the type of cutting that takes place. A pneumatic system moves the end-effector laterally 90° to either deploy the end-effector over the Sorting Table or stow it along side the glovebox wall.

The pneumatic shear end-effector is designed to cut the top off of the bag(s). A manual tool change plate is used to make changing to another end-effector a simple task. Additional end-effectors that are being considered for the WCBO include a hot knife, a cold knife, and a CO_2 laser.

In conjunction with the rotary axis of the Z-Mast, the vertical deployment system allows various types of cuts to be programmed into the system such as circular bottom cuts or spiral cuts around the circumference of the bags.

In some cases the bags do not need to be opened, but simple perforations made to ventilate the bags. This also can be programmed into the WCBO.

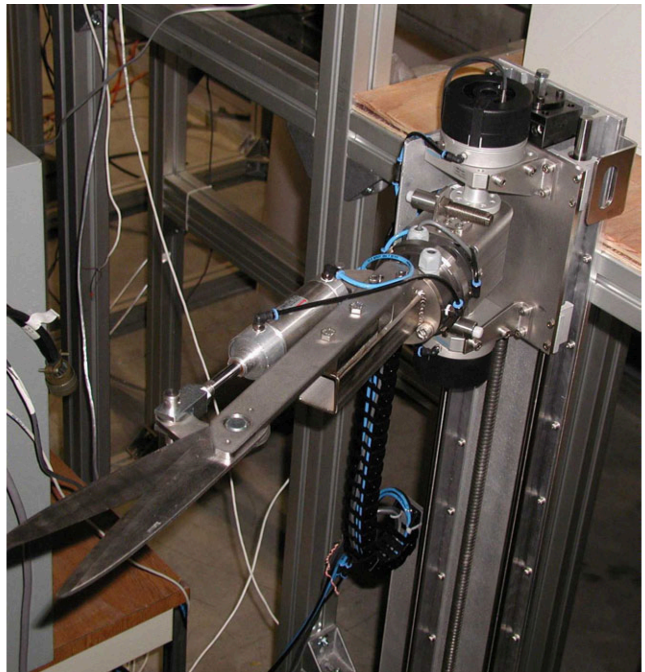

Figure 6. Waste Cut Bag Opener

The waste cut bags will be individually lifted by the j-wrap (the taped opening of a bag) by the XYZR DS and moved over to the WCBO. Flexibility designed into the WCBO will provide an operator with a variety of bag opening options.

4. CONCLUSIONS

The Waste Sorting Station is a stepping stone towards a fully automatic sorting capability. Using the operator to perform tasks he does best such as choosing the objects to be removed from the waste stream and using robotics to do tasks that are difficult, tedious or physically tiring for an operator, an efficient waste sorting system has been designed. This has been accomplished by developing new applications for existing technologies in some cases and has required the development of new technologies in other cases.

Design of equipment that can be used in low level and high level waste applications has been accomplished. This equipment requires low maintenance and is compatible with glovebox operation for repair operations. Where possible, serviceable equipment has been remotely located to minimize in-cell maintenance.

Innovation in 3-D imaging has been achieved at distances and in resolutions and in acquisition times not found in industry. This technology has been developed commercially and is now available at a reasonable cost.

Innovation in utilizing end-effectors and quick change tool plates has resulted in an enclosed system (all cabling is inside the Z-mast) that is easy to maintain and reliable. The concept of multiple end-effectors with one primary end-effector provides flexibility to handle unknown objects efficiently without major modifications to the system. This ensures the system will be not become obsolete because of a waste sorting requirement change.

The integration of all of the Sorting Station components into a system has been done using leading edge commercial software. The protocol and communications through networking provide a flexible, modular design that lends itself to modification without rework. Each software module is independent of other modules and can, therefore, be removed, added or replaced without significant impact to the rest of the system. It also provides access to control functions from various locations, from local control stations or central control room systems.

ACKNOWLEDGEMENTS

Funded under DOE Idaho Operations Office, Contract DE-AC07-991D13727. DOE TRU through both the Transuranic and Mixed Waste Focus Area and the Robotics Technology Development Program.

REFERENCES

[1]Robert Fogel, Robert Milling, Savannah River Site, Aiken, South Carolina

[2] Northern Magnetics Corp., 25026 Anza Drive, Santa Clarita, CA., 91355, USA, TEL: 661-257-0216

[3] NorthStar Technologies Inc., 575 McCorkle Blvd., Westerville, OH, 43082, TEL: 614-891-6909

[4] Costas Charalambous, Gripper Component Sales Manager, Techno-Sommer, 2101 Jericho Turnpike, New Hyde Park, NY 11040, TEL: 516-328-3970

[5] Bill Townsend, President, Barrett Technology Inc, 139 Main Street, Kendall Square, Cambridge, Massachusetts 02142-1528, USA, TEL: 617-252-9000

[6] Angus Tocher, President, VX Optronics Corp., Suite 2000, 777 – 8th Avenue S.W., Calgary, Alberta, T2P 3R5, Canada, TEL: 403-233-2236

[7] Dimension Technologies Inc., 315 Mt. Read Blvd., Rochester, NY 14611, USA, TEL: 716-436-3530

[8] Kaz Mizutani, Assistant Sales Manager, Sanshin Electronics Corp., 12 D, Mauchly, Irvine, CA. 92618, TEL: 949-727-4435, ext. 14.